DOCUMENT RESUME

ED 271 285 SE 046 623

AUTHOR van Lieshout, Ernest C. D. M.
TITLE Developing a Computer-Assisted Strategy Training Procedure for Children with Learning Deficiencies to Solve Addition and Subtraction Word Problems.
PUB DATE 86
NOTE 19p.; Paper presented at the Annual Meeting of the American Educational Research Association (70th, San Francisco, CA, April 16-20, 1986).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Addition; Computer Assisted Instruction; Elementary Education; *Elementary School Mathematics; Foreign Countries; *Learning Disabilities; Mathematics Instruction; Mental Retardation; Problem Solving; Secondary Education; *Secondary School Mathematics; *Subtraction; Training; *Word Problems (Mathematics)
IDENTIFIERS Mathematics Education Research

ABSTRACT

Two training procedures were constructed to teach children with learning deficiencies to solve simple addition and subtraction word problems. Each training procedure was evaluated in a separate multiple baseline design across subjects. The experiments were designed to prepare for the development of computer assisted training programs. Two female mildly retarded children (age 14) participated in the first experiment. They were taught to work systematically through the problem task and to pay attention to several important components of the problem text. The training procedures turned out to be effective. Research was continued with a computer assisted training experiment. The computerized training procedure is described in relation to the findings of the first experiment. The second experiment was run with three male disabled children (age 10-11). They were taught to draw a diagram as an external representation of the problem. The diagrams reflected the properties of "change," "combine" and "compare" problem types. This training method appeared to be effective as well. The differences in the nature of the efficiency of these two training methods was discussed. The results were analyzed by graphing correct problems, mean response time, number of errors, and mean percentage of correct steps over training sessions. (Author/JM)

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DEVELOPING A COMPUTER-ASSISTED STRATEGY TRAINING PROCEDURE FOR CHILDREN WITH LEARNING DEFICIENCIES TO SOLVE ADDITION AND SUBTRACTION WORD PROBLEMS

Paper presented at the annual meeting of the AERA
16 April 1986 in San Francisco.

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Developing a computer-assisted strategy training procedure for children with learning deficiencies to solve addition and subtraction word problems

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Abstract

Two training procedures were constructed to teach children with learning deficiencies to solve simple addition and subtraction word problems. Each training procedure was evaluated in a separate multiple baseline design across subjects. The experiments were designed to prepare for the development of computer assisted training programs. Two female mildly retarded children (age 14) participated in the first experiment. They were taught to work systematically through the problem task and to pay attention to several important components of the problem text. The training procedure turned out to be effective. Research was continued with a computer assisted training experiment. The computerized training procedure is described shortly in relation to the findings of the first experiment. The second experiment was run with three male learning disabled children (age 10-11). They were taught to draw a diagram as an external representation of the problem. The diagrams reflected the properties of "change", "combine" and "compare" problem types. This training method appeared to be effective as well. The differences in the nature of the efficacy of these two training methods was discussed.

Introduction

Absence of adequate information processing strategies and lack of metacognition have become important explanations of the poor performance of learning disabled and mildly retarded children in academic skills (Hall, 1980; Sternberg, 1981). Laboratory research and teaching experiments have shown that these children are able to learn an adequate task or a problem solving strategy (Brown, Campione, & Day, 1981; Hall, 1980; van Lieshout, 1984). This was accomplished by instructing and training an adequate task strategy and by making the children aware of the cognitive operations they needed. The monitoring and correction of the task behavior by a trainer ask for an individual training situation. Mostly such training procedures are very tedious and time consuming, so this type of instruction does not fit in very well with classroom settings. The use of a microcomputer can offer a solution to these problems. Apart from this practical use computerized training of course offers comprehensive data acquisition facilities and asks for a formalization of the training procedure which facilitates replicability.

The study of the relation of instruction variables and the way in which children with learning deficiencies solve arithmetic word problems has several

advantages. First of all the task of solving a simple addition or subtraction word problem contains several steps of a strategy (De Corte, Verschaffel, & De Win, 1985) and demands (probably for novices in particular) awareness of this strategy. The poor performances of children with learning problems in solving simple addition and subtraction word problems (Bilsky & Judd, 1986; Goodstein, Cawley, Gordon, & Helfgott, 1971) may partly be explained by a lack of problem solving strategies and planning skills (Hall, 1980). Because of this the study of word problem solving by these children and the way in which their problem solving processes can be improved is one of the areas that could contribute to the understanding of learning disorders. Important too is the study of the possibilities to enhance mathematical knowledge in this population of children. This knowledge could be facilitated when formal mathematical representational procedures are linked to the semantic structure of word problems (Moser & Carpenter, 1982).

Until now we have developed two types of instruction. The first one teaches the pupil a general, attention directing approach to solve a word problem. The second approach is more tied to the specific semantic scheme underlying the problem. To prepare for the computerized training experiments several pilot studies have been carried out. Some results will be presented in this paper. Until now a computer program has been written only for the first training procedure. An experiment to investigate its efficacy is running now.

EXPERIMENT 1

A training procedure to pay attention to the componential and sequential structure of a word problem solving task[1]

De Corte et al. (1985) proposed a model for solving simple word problems. The first stage in this model is the construction of an internal semantic representation by reading the problem text. For experienced word problem solvers, the information they read is processed in a top-down direction: they try to fill in one of their schemes available. Novices do not have these schemes and have to build a representation bottom-up: perhaps all they read is equally important for them. So a difference between experts and novices could be the availability of domain specific knowledge that guides the information selection.

Pupils with learning disorders more often than regular pupils, have an impulsive style of responding caused by a lack of strategic and metacognitive knowledge (Digate, Epstein, Cullinan, & Switzky, 1978). This could lead to unequal distribution of attention during intial reading. Garofalo and Lester (1985) asked for the attention of mathematics researchers for the relation between metacognition and mathematical performance. They pointed to the convictions of third and fifth graders that "...verbal problems can be solved by a direct application of one or more arithmetic operations and that the correct operations to use can be determined merely by identifying the key words... (p. 167)." Slife, Weiss an Bell (1985) showed that learning disabled children with poor mathematics performance were less skilled in metacognition than

[1] This experiment was designed and run together with Gert Anbeek. Annette van Grinsven trained the children and assisted in other parts of the experiment as well.

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regular pupils. Goodstein et al. (1971) presented their subjects with word problems containing extraneous information. This was information that was not relevant to the solution of the problem. Their results led "...to the interpretation that many educable mentally retarded children do not, in fact, "read" verbal addition problems, but rather select all numbers contained in the problem..." (Goodstein et al., 1971, p. 241). Possibly the attention of children with learning disorders is attracted mainly by the numbers and maybe by some key words in the problem text.

In the present experiment mildly retarded children were trained to analyze the problem text systematically and to proceed with the problem solving task in a similar vein. The training procedure was not intended to direct the children's attention explicitly to the construction of a representation of the problem. The purpose of the training method was rather to have the child select the information necessary for the construction of such representation and to have the child pay attention to several components of the problem solving task.

Method

Design and subjects:

Two mildly retarded girls (age 14) were trained in a (modified) multiple baseline design across subjects (Kratochwill, 1978). They could read aloud correctly, solve addition and subtraction sentences with the numbers and the correct answer lower than ten, and had the lowest performances in word problem solving of their class. For each child a baseline was made. If the baseline was stable, the training was started. When training had been stopped there were "probe sessions" to establish their performances under the same conditions as in the baseline phase.

Materials:

Each session nine addition and subtraction word problems were presented to the children. Six problems contained irrelevant information, the three others did not. The nine problems were equally distributed over three types: change, combine and compare. The position of the unknown was varied but the combination of the factor relevance and the factor type was held constant over sessions. All numbers and the correct answer were below ten. The problem texts were printed on separate cards. An example of a problem (with irrelevant information) is:

> Susan has 3 marbles. John has 1 marble. Paul has 2 marbles more than Susan. How many marbles has Paul?

During the instruction and training phase an additional card was presented. On this card a so-called "planning list" was typed. This list consisted of seven labels. Each label consisted of one to three words (in Dutch) and described one of the steps of the task strategy. These steps were: "read" (read the problem text), "ask" (what is asked?), "kwow" (what do you know already?), "numbers" (which numbers do you need?), "sum" (formulate a sum), "answer" (what is your answer?) and "check" (check your answer). The steps were listed at random in a vertical array. Every word problem was accompanied with another random sequence of step labels.

Procedure:

During the baseline and probe sessions the child had to solve the problem without any help of the trainer. The answer and the response time were recorded.

Instruction. At the start of the training phase there were three instruction sessions. First the trainer performed the task strategy to offer a model for solving the problems. Next the problems were tackled both by the trainer and the child. Finally the child had to perform the task alone. The instruction phase aimed at revealing to the child the steps in the stategy and the type of responses the trainer expected during the subsequent training phase.

Training. After the instruction session the training phase followed. Each of the nine presentations of a word problem in a training session was accompanied with a planning list. In order to prevent the child from choosing a label solely on account of its position in the list instead of selecting it on semantic grounds, the order of the step labels in the list was randomized and was different for each new presentation of a word problem.

The child had to announce his next step of the task strategy by pointing to the step label. The steps had to be executed in a fixed order. For example, when the child was presented with a new problem text, she first had to point to the step "read". When the child pointed to another step label than she was supposed to, the trainer said: "This is not the good one, try again." When the child failed once more the trainer said while pointing to the correct step name: "It has to be this one, point at it." In the example the child had to point to the label "read". So the child could not proceed any further before having chosen the correct step.

After the child had selected the correct step, the trainer confirmed the correctness of the choice and repeated in a short phrase the meaning of the step. For example: "Good. Read the problem carefully." Next, the child was allowed to execute the particular step. When the child subsequently did something else than she was supposed to, for example giving an answer instead of reading the text, the trainer ignored the content of this reaction and repeated the short description of the purpose of the step.

The order and the contents of the steps were:

1. *Read*. The child had to read the text. If she completed this step within three seconds she would have to read the text once more.
2. *Ask*. In this step the child had to point to specific words in the sentence that contained the question. It concerned the words which described the attributes of the unknown set. In the sentence: "How many marbles has Paul?", "marbles" and "Paul" were the obligatory words. It was not allowed to choose words from other parts of the problem text. When the child pointed at the right words, she could proceed with the next step. If she made a mistake, she would receive feedback from the trainer. For example, when the child pointed only to "Paul", the trainer said: "That isn't enough, try again." When the child again made an error, no matter what error it was, the trainer said: "It had to be these ones," and pointed to the obligatory words.
3. *Know*. The structure of this step was similar to the previous one. In this case the child had to point to the specific words in the two other (known) sets. This time the obligatory words described first of all the person who owed or had received or lost something, secondly the verb or auxiliary, and finally the number of each set. When the problem consisted of a comparison, both the person with whom the comparison was made (the comparison always concerned persons) and words as "more" or "less" had to be pointed to. (This could also have been the case in the previous step.) In

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the sentence: "Susan has 3 marbles. Paul has 2 marbles more than Susan," the obligatory words were: "Susan", "3", "Paul", "2", "more", and "Susan". When words were chosen from the question sentence or from irrelevant information (in the example given previously: "John has 1 marble.") the trainer said: "This isn't correct yet, think again." The feedback was of the same, two-level type as in step two.

4. *Numbers.* Again this step had the same structure as the previous two. The child had to point to the two numbers which she needed to obtain the solution.
5. *Sum.* The child had to formulate a sentence such as: "3 + 2 =" in his own words. Again mistakes were followed by two-level feedback. (The children were unable to solve or to use open sentences like: "4 + . = 6".)
6. *Answer.* Any numerical answer was accepted. No feedback was given. The only thing the trainer said was: "Go ahead."
7. *Check.* As in most of the other steps the child got two chances to answer if required. After the first mistake the trainer said: "Have a close look once more." When the child made a mistake again the trainer said: "It has to be ..." (in the example: "5").

Every step which was completed successfully was followed by a remark of the trainer like: "Good".

We acknowledge the fact that our choice of obligatory words is more or less arbitrary. The purpose of this part of the training procedure, however, was to have the child visualize to the trainer (and in the computer version to the computer) whether she had localized specific information in the problem.

In the next phase of the experiment the child had to solve the word problems in probe sessions, which in fact had the same conditions as the baseline phase.

Results

Figure 1 shows the main results. The curves with the solid circles show the number of correct problems completed in the sessions with no training. Subject 1 clearly performed on a higher level (59% correct) in the first probe phase after training, compared to her baseline (20% correct). She maintained this high level in the second probe phase (74% correct) and even in the third one (70% correct), which followed the training phase several months later. Subject 2 also showed a clear increase in performance from the baseline phases (20% and 23% correct) to the first probe phase (82% correct) after training. Her performance level in the last probe phase (44% correct) was also higher than her baseline performance, but she did not retain the high level of the first probe phase.

The curves with the open circles show the number of correct problems completed during the training sessions. These problems were only scored correct, if all steps of the task strategy had been performed without any intervention of the trainer. According to this scoring criterion both children improved their performances during the training phase. Figure 2 shows an increase in response time from the baseline to the probes after training in the data of both children.

The children had to proceed through the steps of the task strategy in a strict order. After the step "reading" for example, "answer" was a wrong choice and "ask" was the right one. Table 1 shows a decrease in the number of wrong first choices (maximum seven) from the first to the last training session for each of the two children.

A child could also make an error in the execution of a particular step. Pointing to words with irrelevant information was such an execution error. Table 2 shows the number of correct steps completed, averaged over the two children. Generally the number of correct steps executed appeared to increase. As can be seen in the table, the step "sum" was a clear exception.

Discussion

The training procedure led to the expected improvement in the ability to solve simple addition and subtraction word problems. It is important to note that this improvement took place without direct training of the ability to represent the problem somehow. There were only two subjects in this study, but the results of two recent training experiments carried out in a similar vein seem to support this conclusion.

As Figure 1 shows, child 1 scored low on the first probe session. Maybe this was a result of the sudden transition from the training phase with much aid of the trainer to the first probe session without any help. To prevent this effect the aid of the trainer should decrease perhaps more gradually.

After training the children responded slower and with fewer errors than in the baseline period. The increased response time is possibly a sign of the growth of a more elaborate task strategy with less missing components. The relatively fast responding with many errors in the baseline is a known phenomenon in the research on cognitive impulsiveness (Kendall & Finch, 1979). Cognitive impulsiveness is a "trait" which is often attributed to a lack of self-contol, strategic behavior and metacognition (Meichenbaum & Asarnow, 1979; Meichenbaum & Goodman, 1971; Kendall & Finch, 1979). A part of these skills could have been improved by the present training procedure. There is no clear evidence for this presupposition, but the tendency to improve the choice of the next step in the task strategy during training (see Table 2) is in accordance with this hypothesis.

In the execution of the steps there was a marked lack of improvement in the step "sum". The correct execution of this step most problably reflects the success with which a child can transform its semantic problem repesentation in a formal arithmetical sentence. But when the semantic representation is still insufficient, feedback about the correctness of the sum she proposed is rather meaningless. It seems that the upper limit of the training effect was determined by the child's ability to represent the problem correctly. This is in agreement with the conclusion of Bilsky and Judd (1986). They compared the performances in word problem solving of retarded and non-retarded children. Bilsky and Judd found evidence for the conclusion that the ability to understand and represent problems, possibly plays an important role in the differences in performance of the two groups.

The efficacy of the present training method possibly consisted of the creation of conditions (such as selecting required and relevant information, recalling important steps and so on) that are favorable for the efficient use of or are complementary to the already existing but not fully developed problem solving strategies.

The computer assisted instruction program. The results of this study supported the contention that it would be worthwhile to carry on this type of experiments with a computer assisted training program. Especially the usefulness of pointing behavior as an index of (a part) of the ongoing problem solving behavior seemed promising for computerized training. An experiment with nearly the same training procedure is running in a computerized version.

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The instruction sessions with a human trainer have been maintained but the trainer has been replaced by the computer in all training sessions (as well as in the baseline and probe sessions). The hardware consists of a microcomputer (Apple IIe, 128 Kb) connected to a touchscreen (Philips VP120). The software has been written in Pascal.

The problem text and the planning list are projected on the touchscreen monitor. The child has to touch a step label on the screen when he wants to choose the next step. A short sentence on the screen and highlighting of one of the step labels are used for corrective feedback. During the execution of the steps "ask", "know" and "numbers" the child has to touch the specific words or numbers in the problem text. The same type of corrective feedback is given as is the case when choosing incorrect step labels. The input of numbers takes place with the aid of "softkeys". For the steps that need this type of input ("sum", "answer" and "check") the screen displays an array of numbers and signs ("+", "-" and "=") in boxes which can be touched. So touching is the only mode of responding. The user-interface in this training procedure frees the learning disabled or mildly retarded child from using a keyboard. They can focus their attention on the problem itself and do not need to worry about finding the correct keys and making spelling errors.

Later this training procedure will be extended with more direct training of the use of an external problem representation. The following study is a first pilot experiment (without computer) to develop such training.

EXPERIMENT 2

A training procedure to use a correct problem representation of addition and subtraction word problems.[2]

Study 1 contained some evidence that training which is not occupied with the problem representation of the child will not always be sufficient for having the child achieve a more complete understanding of the problem.

It is not sure whether these retarded children ever had the problem solving strategies (such as modeling with materials or fingers and counting) in the same degree as regular young elementary school children apparently have (Carpenter, Hiebert, & Moser, 1981,1983; Carpenter & Moser, 1984). These retarded children may never have had these strategies or have lost a major part of them. Any help to have these children represent the semantic structure of word problems could improve their performance. Lindvall, Tamburino and Robinson (1982) developed a method which teaches subjects to draw a diagram to represent a specific word problem. There was a different diagram for each of the eight problems types, which were variations of four basic types: combine, change, compare, and equalize.

The present study in part replicated the Lindvall et al. study but differed in several other aspects. First of all to be able to be a pilot study for future experiments with computerized training, the training procedure had to be more formalized than that of Lindvall et al. In the second place we wanted to validate the training effect with more experimental rigor than the "one-group pretest-posttest design" (Campbell & Stanley, 1963) which Lindvall et al. quite justifiably used in their exploratory investigation. Finally, we had to

[2] This experiment was run in cooperation with Lucia Schulpen.

find out whether such training would work with children with learning deficiencies.

Method

Design and subjects:
Three male learning disabled children were trained in a multiple baseline design across subjects (Kratochwill, 1978). Their ages ranged from 10 to 11 years old. The selection procedure was the same as in study 1, except that special attention was given to their ability to understand words like "more", "less", "together" etc. Unlike study 1, a probe session was inserted after each two training sessions in the training phase.

Procedure:
The same type of problems was used as in study 1, with only one exception: all problems contained irrelevant information. In comparison with Lindvall et al. (1982) only the equalize problems were absent. During the baseline and probe sessions the child received only feedback about the correctness of his solution.

Instruction. At the start of the training phase there were two instruction sessions. As in study 1 the trainer showed the child the task strategy. The trainer used small cubes to represent the problem. The first instruction session contained no irrelevant information. The trainer drew lines around the cubes to mark the different sets. In the second session the cubes were replaced by dots and irrelevant information was added. As in study 1 the instruction phase was to make the child understand what type of activities he was expected to do in the training phase.

Training. During the sessions of the training phase, after the presentation of the problem text the child had to draw a diagram. The diagrams resembled the ones Lindvall et al. (1982) used. In the present experiment the child first had to represent the number of one of the known but relevant sets. He had to finish this step by drawing a circle (or an oval) around the dots of this set. Next he had to represent the second known but relevant set. In some cases the child only had to draw a second circle around a part of the dots drawn before. This was the case when for example the first represented set was the whole in a combine-type problem. In other cases new dots had to be made. Next a circle had to be drawn around this new represented set.

The dots for the representation of a change-type problem had to be placed in one row. For the combine type the dots for the representation of the two parts were to be placed in two rows below each other. In the problems of the compare type the two comparison sets had to be drawn in two rows below each other as well. To be able to compare the number of dots of the sets with each other in the latter problem type, each dot of the smallest comparison set had to be placed just below or in top of a dot of the largest comparison set. These dots were to be connected with each other by a vertical line. The last step with each of the poblem types was to draw a rectangle around the dots of the unknown set to form the final answer. Figure 3 shows an example of the diagram made for the representation of a compare problem.

The trainer observed the drawing behavior of the child and gave standardized feedback on each step in the execution of the strategy. When the child made a first mistake the first level feedback was given, for example: "It

does not say two pencils, but two pencils more," or "The number is correct, but the dots have to be placed below each other." When the child again failed the trainer showed the correct operation.

Contrary to the baseline and probe sessions in which the child had to respond with only a numerical answer, the trainer considered the number of dots in the rectangle as the final answer in the training sessions.

Results and discussion

Figure 4 shows the number of correct problems completed. Child 1 showed a sharp increase in performance from the baseline to the probe sessions in the training phase (curve with solid circles). He retained his high level up to the follow-up sessions, which took place half a year after the training phase. The curves (with the solid circles) of the other two children also showed an increase in performance in the probe sessions of the training phase in comparison with the baseline. But this is not as clear as with the first child. To seek additional support the data of the baseline and probe sessions (during training) of the latter two children were subjected to a time series analysis (Tryon, 1982, 1984). As expected there were no significant trends in the baseline data of child 2 (z = -.256, n = 12, *ns*) and child 3 (z = 1.359, n = 20, *ns*), whereas the subsequent change in performance during the probes in the training phase (compared with the baseline) did reach significance in each of the children (respectively z = 2.976, n = 18, $p < .01$ and z = 3.607, n = 26, $p < .01$). Child 2 lost a great deal of his gain after some untrained probe sessions. The follow-up performance of child 2 and 3 were both lower than their last performance level during the training probes, but still higher than the baseline. The training curves with the open circles (see Figure 4) show increasing proficiency of the children to conform to the rules for drawing a correct diagram.

The results support the earlier findings of Lindvall et al. (1982). It is clear too that learning disabled children can improve their word problem solving performances as a result of this type of training.

General discussion

Two types of training procedures were constructed and evaluated. The first one tried to teach the children to proceed systematically through the problem solving task stepwise while carefully paying attention to the problem text. The training procedure aimed at making the children aware of these steps. The second training procedure tried to teach the children to construct an external problem representation through the drawing of a diagram. Both training procedures turned out to be effective. The mildly retarded and learning disabled children seemed to benefit from these training procedures. Because there were only two and three subjects, replication is needed to substantiate the findings.

Both training procedures seem to have their advantages and disadvantages. The first procedure is perhaps more general and less tied to specific types of word problems, but there is no help for deficient representation skills. The second procedure does give this aid, but it is rather specific for the problems trained. A combination of both types is scheduled.

Further research has to investigate the supposed differences in efficacy. It may be interesting to study the possible differential transfer effects on several other variables such as untrained types of arithmetic word problems. It can be hypothesized that the first training method will facilitate the production of correct answers on non-trained problems types whereas the second training procedure could cause a larger training effect on the word problems trained. Additional research is also required to figure out whether there is some profile of subskills which ask for specific components in the training procedure. For example some children may only need training in representational skills, whereas others would need a type of training as used in study 1.

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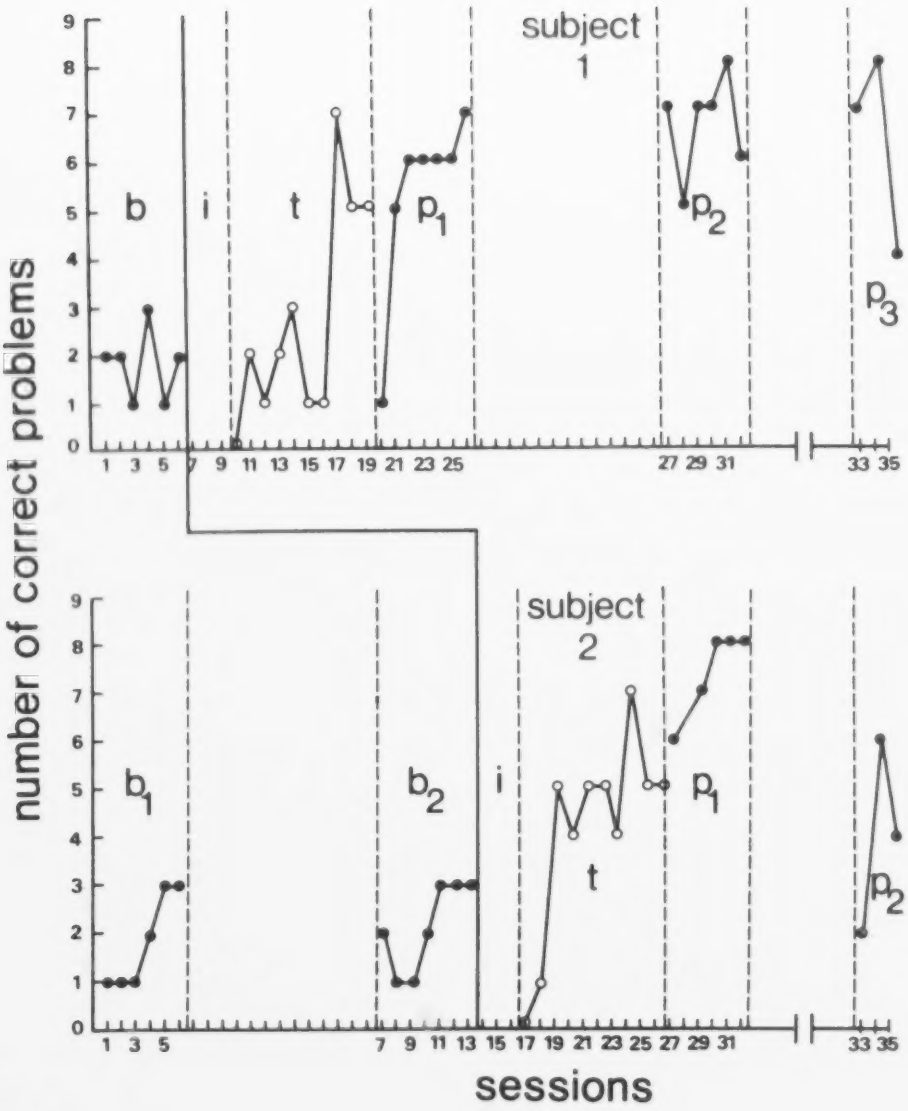

Figure 1. Number of correct problems completed in each session for each experimental condition and for each of the two children. b = baseline, i = instruction, t =training, p = probe. Solid circles: performance during the non-training sessions, open circles: performance during training sessions with the additional criterion of all strategy steps correct.

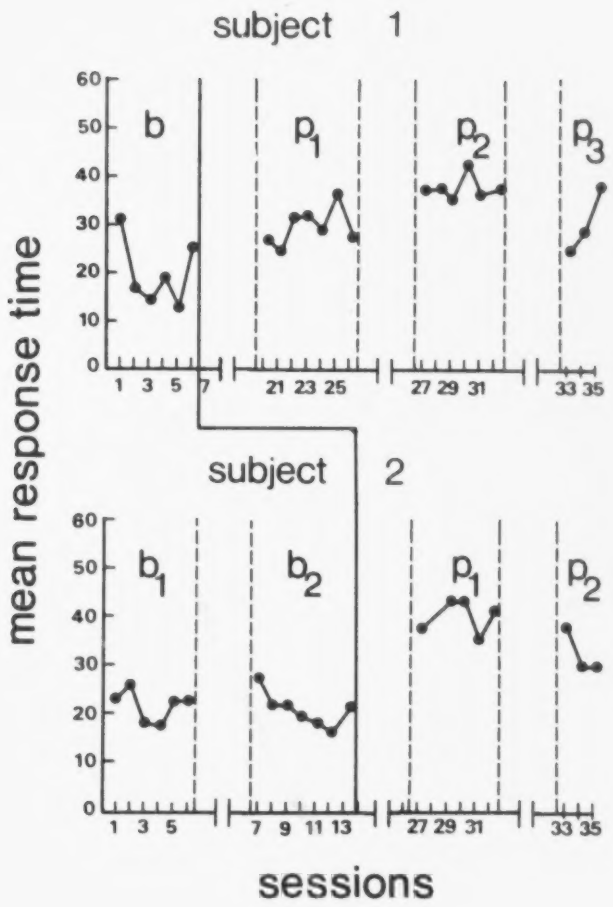

Figure 2. Mean response time in each session for each experimental condition for each of the two children. b = baseline, p = probe.

Paul had 2 pencils, John had 1 pencil, and Susan had 6 pencils. How many more pencils did Susan have than Paul?

1.

2.

3.

4.

5.

6.

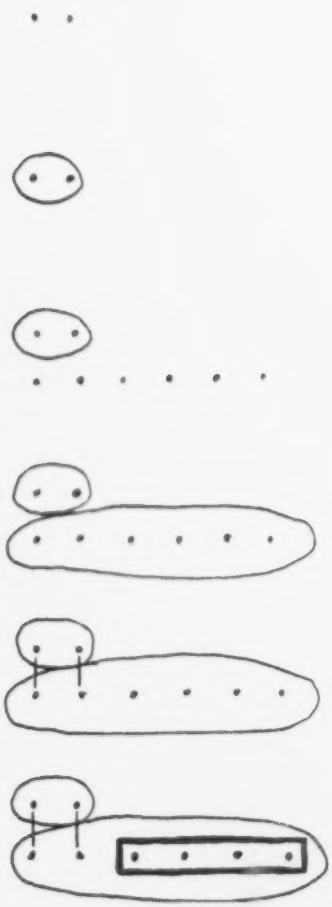

Figure 3. Example of the drawing of a diagram.

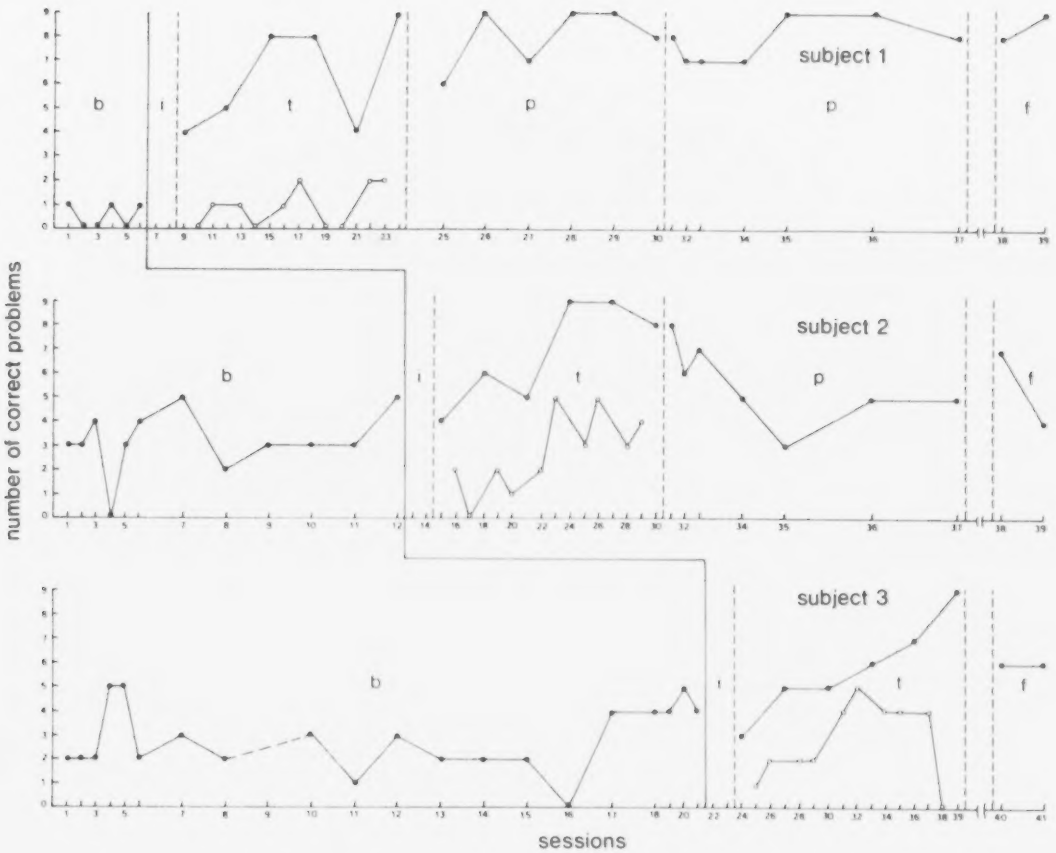

Figure 4. Number of correct problems completed in each session for each experimental condition and for each of the three children. b = baseline, i = instruction, t =training, p = posttest. Solid circles: performance during non-training sessions, open circles: performance during training sessions with the criterium of all strategy steps correct.

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Table 1
Number of errors in the sequence of the steps of the task strategy.

Training session		1	2	3	4	5	6	7	8	9	10
Number of errors	Child 1	4	2	5	2	0	0	1	0	1	0
	Child 2	4	3	0	1	0	0	0	0	0	0

Table 2
Mean percentage of
correct steps completed in each training session
(averaged over the two children).

step	training session									
	1	2	3	4	5	6	7	8	9	10
ask	78	83	94	100	100	94	100	100	100	94
know	6	44	56	56	61	61	67	78	72	83
number	78	89	94	94	94	94	94	100	100	94
sum	61	39	72	61	67	56	56	83	72	61
answer	89	94	100	100	100	94	100	100	100	100
check	89	94	100	100	100	94	100	100	100	100

Note.-The step "reading" is not included because it was always completed correctly.